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UNITED STATES DEPARTMENT OF AGRICULTURE

BULLETIN No. 300

Contribution from the Office of Public Roads and Rural Engineering
LOGAN WALLER PAGE, Director

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Washington, D. C. PROFESSIONAL PAPER November 10, 1915

EXCAVATING MACHINERY USED IN LAND DRAINAGE

By

D. L. YARNELL, Drainage Engineer

CONTENTS

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By D. L. YARNELL, *Drainage Engineer*.

CONTENTS.

INTRODUCTION.

The excavation of nearly all drainage ditches, other than mere field drains, and a large part of the levee work are now done by power machinery. In the carrying out of community drainage projects in agricultural districts it is often the case that persons upon whom must devolve the ultimate responsibility for the correct design and proper prosecution of the work are but little experienced in the applicability of the different types of excavating machines, and have little practical knowledge of the methods and cost of operation of such machinery. This is frequently true of county drainage commissioners, drainage district commissioners, and of local engineers who, though of limited experience in the technicalities of ditch and levee construction on a large scale, are nevertheless, by virtue of their office, called upon to originate or pass upon plans for drainage improvements, draw up specifications, and award contracts. It is for the purpose of supplying information that would be useful in such cases that this bulletin has been prepared.

In obtaining the information embodied in this bulletin the writer has been aided materially by data furnished by private engineers in charge of improvements and by various contractors and manufacturers.

NOTE.—This bulletin is of interest to those who have to do with the installation of systems of drainage; it is suitable for distribution in the eastern part of the United States.

The various publications of the different manufacturers of excavating machinery have also been freely consulted, and a number of projects under construction have been inspected.

DEVELOPMENT OF EXCAVATING MACHINERY.

Open drains were no doubt dug on wet agricultural lands during the early settlement of this country. Since only hand tools were then in use, the ditches were small. If the channel was too large to permit the material to be dug and thrown out in one operation, it was necessary to rehandle the dirt with shovels or to carry it out in baskets or wheelbarrows. These methods were very slow and expensive. Although the ditches then constructed served their purpose for the small agricultural tracts which were generally on high ground, the increase in population and the resulting spread of agricultural operations to the lower lands soon demanded the construction of larger channels. Teams and scrapers were then used where conditions permitted. If the material was hard it was first loosened with a plow and then removed by means of slip or wheel scrapers. This method, however, became too expensive as larger ditches were required. Moreover, drainage channels must frequently be constructed on lands so wet and soft as to preclude the use of teams. The increasing demand for suitable excavating machinery has engaged the attention of many men of mechanical bent, and the result has been the invention of modern types of machinery, the development of which has been rapid. By the use of modern machinery the cost of drainage work has been so reduced as now seldom to afford valid excuse for failure to drain.

Perhaps the first successful use of power machinery in drainage work was on a project in Illinois in 1882 when a floating dredge was used for digging the channels. During the early development manufacturers entered their machines in contests for medals offered for the best digging machines. Thus in 1886, three dredging concerns entered their machines in such a contest before the Illinois State Board of Agriculture.

The early type of dipper dredge was equipped with the old-fashioned vertical spuds, and the hull was built wide to prevent tipping. The ditches desired at that time were usually small and owing to the width of hull the operator was nearly always compelled to excavate more material than he was paid for. The bank spud, which runs directly from the side of the machine to the bank, was invented to do away with this unnecessary width of hull and the consequent useless excavation. Although many delays and difficulties were encountered in the early stages of development, the cost of excavation by machinery was soon reduced far below that by hand labor. This period marks an epoch in the progress of drainage in this country.

In late years the so-called dry-land excavators of various types have been developed and have reduced the cost of excavation under conditions to which floating dredges are not adapted. The growth of the drag-line scraper excavator has been especially prominent. At present this machine probably has a wider field of usefulness than any other type of excavator made.

The cost of all kinds of excavation has now reached a very low figure as compared to the prices prevailing for work by machinery only a few years ago. This has mainly been brought about by the entrance into the contracting field of many men equipped with modern machinery who, through the keen competition, have taken contracts at prices permitting only a small margin of profit.

THE FLOATING DIPPER DREDGE.

The floating dipper dredge is probably the oldest and most widely used type of machine for the excavation of drainage ditches. The essential parts are the hull, engines, boiler, A-frame, swinging circle, spuds, boom, and dipper. With the exception of the dipper these parts appear in some form on every type of floating dredge used for ditching. Various manufacturers have different patented details of construction, but the general principles of construction and operation are the same on all floating dipper dredges.

ESSENTIAL FEATURES OF CONSTRUCTION.

HULL.

The hull may be either of wood or of steel; the use of the latter material will undoubtedly constantly increase in the future owing to the ever-increasing cost of timber that is suitable for building hulls. The many difficulties met with in the operation of the earlier machines have taught manufacturers that certain fixed relations exist between the dimensions of the hull and the positions and weights of the other parts of the dredge. Unless these relations are considered in the design of the hull much trouble will result in the operation of the dredge. The smaller dredged ditches are generally constructed by machines with from 1 to 1½ yard dippers. The machinery necessary for operating these sizes being comparatively light, the hulls are of such dimensions that they can easily be floated in the smaller channels, although the width of hull used for a machine of given capacity varies somewhat with the different manufacturers. Some dredges are so designed that the thrust of the dipper, when digging, is carried directly from the A-frame through the spud arm to the spud shoe and the bank of the ditch. By this arrangement a slightly narrower hull can be used than is necessary where the machine is differently designed.

A dipper dredge to withstand the severe stresses due to the constantly changing loads must be very strongly built. If the hull is of wood it is made up of a strong frame work of timbers planked on the sides and bottom with 3-inch (or heavier) planks. It is always strengthened with numerous cross trusses inside, to prevent buckling. The front end of the hull should always be of double thickness to prevent damage and possible sinking through the dipper striking the hull.

In the larger sizes of dredge built at the present time the common practice is to make the hull of the same width, top and bottom. On some of the smaller machines, especially those with steel hulls, the top is made wider than the bottom. Hulls must be very carefully caulked, since in operating the dredge the strain on the hull will tend to loosen any poor caulking.

It often becomes necessary to dismantle a dredge in order to move it from one project to another. Wooden hulls, because of the necessity of their being so strongly built, are practically destroyed by being taken down, and it is in many instances cheaper to build a new hull than to move and rebuild the old one. To save this expense steel hulls are used to some extent on the smallest-sized machines, although they have not been generally favored for the larger dredges. On some of the small one-half yard or three-fourths yard dredges the hull has been made in sections, which can be taken apart and hauled or shipped to another project. This method, however, is not adapted to the larger machines.

The machinery of a dredge is ordinarily placed on the deck of the hull. It is, however, sometimes placed below the deck in order to gain head room. Sometimes the boiler and coal bins are placed on a deck from 1 to 3 feet lower than the main deck.

ENGINES AND BOILER.

The power most commonly used on dipper dredges is steam, although a number of machines are now in operation which are equipped with internal-combustion engines or electric motors. The majority of dredge operators are more familiar with steam plants than with oil engines. Also, steam power has the advantage of being good for from 50 to 100 per cent increase over its rated capacity.

Internal-combustion engines are generally run on either gasoline, kerosene, naphtha, or distillate oil. Practically all of the dredges equipped with this type of engine are of the one-half yard or 1-yard size, although it has been used in at least one instance on a 3-yard machine. An internal-combustion engine is usually rated at its actual capacity. Therefore, when replacing a steam engine with a gas engine, it is a good plan to put in a plant with from 50 to 75 per cent greater power than the rating of the steam engine which it is to replace. Contractors as a rule do not consider internal-combustion

engines as suitable for operating machines which have such constantly changing loads as is the case with dipper dredges.

Owing to the constant jar and pound on the hull the vertical engine is not so well adapted to excavating machinery as the horizontal type. On a large dredge an independent engine unit is used for each of the operations of swinging, hoisting, and handling spuds. The hoisting and swinging engines are generally of the horizontal, double-cylinder type and must be self-contained on a cast-iron or structural-steel bed plate. Steam engines are generally designated by the dimensions of their cylinders rather than by the horsepower they develop.

Owing to the cost of fuel, the expense of transporting it to the dredge, and the impure and muddy water that must be used in some cases, the size and type of boiler must be selected with great care. The boiler commonly used is the locomotive type with either open or water bottom. Vertical boilers have been used in dredges of the smallest sizes, but are not economical in the consumption of fuel. The grate area of the locomotive-type boilers is ordinarily less than that for the same size of Scotch marine boiler. The return-flue Scotch marine boiler is used on many dredges and meets with great favor. The earlier boilers were designed for a pressure of 100 pounds. Later this was increased to 150 pounds and the boiler was worked at 100 pounds or more pressure. The size of boiler should be at least 25 per cent greater than that theoretically required to operate the engines. Owing to the foul character of the water that must often be used, the boiler should have two separate and distinct boiler feeds, either injectors or pumps. A great saving of fuel can be effected by covering the boiler and steam pipes with asbestos. Either wood or coal is used for fuel.

A-FRAME.

The A-frame is a tower composed of timber or steel members securely anchored on the deck of the hull near the front and joined at the top by a cast-steel head or yoke. (See Pl. I.) The A-frame may have either two or four legs. In the latter case the two front or main legs are set in a vertical plane. If only two legs are used they are inclined slightly forward. The A-frame must be strongly guyed and held rigidly in position, as the severe stresses from the outer and loaded end of the boom are carried by the top of this tower. Failure of any part of the A-frame may result in serious damage to the dredge and even in loss of life. The height is governed by the required elevation of the end of the boom, which in turn is determined by the depth of excavation and the distance at which the excavated material must be placed. On the top of the head block is a large pin on which the yoke revolves, this latter being a short beam to the ends of which are attached the cables which support the outer end of the boom.

SWINGING DEVICE.

The swinging device used on the different makes of dredge varies greatly. In some cases it consists of a circular, double-channel frame, firmly anchored to the deck, with several sheaves bolted at intervals in the circumference of the frame to carry the cable that travels over them in swinging the boom. In this fixed type of swinging device a large diameter of circle can be used. There is also the movable type of swinging circle. This generally consists of a solid iron circle mounted on a pivot. The heel of the boom is over the point of the pivot and the boom is braced to the circle. This type requires more deck room than does the first named type. The turntable may be placed on deck (Pl. I, fig. 1) or overhead (Pl. I, fig. 2), but the deck plan is generally used.

Independent engines may be used for swinging the boom or power may be obtained from the main engine to drive the swinging drums. If this latter plan is followed two independent friction drums are attached to the bed plate of the engine and geared so as to be driven by it. If internal-combustion engines are used, independent friction drums are necessary for the various operations of the dredge. The common practice on large steam-operated machines is to have independent swinging engines.

SPUDS.

Spuds are heavy timber or steel members, the purpose of which is to hold the dredge in position while operating. One is placed on each side near the front and the third in the center line of the boat at the stern. Vertical spuds extend directly downward at the side of the hull and rest on the bottom of the excavated channel. They are used on deep-water dredges or for excavating large channels.

For a dredge with a narrow hull bank spuds, which extend outward and rest on the ground surface, are preferable, since they give a large bearing surface and the footing is usually on solid ground. These are important features, as a longer boom and a larger bucket can then be used on a narrow hull.

There are various patented types of bank spuds. One is the convertible bank-and-vertical power spud. This type can easily be changed from a bank into a vertical spud and is most convenient in crossing old channels, digging cut-offs, or making a double cut. Another type is the telescopic bank spud, so designed that the spud is either lengthened or shortened by means of a telescopic device. There are other styles of bank spuds, which, although they possibly do not have as wide a range as the telescopic type, can, nevertheless, be operated successfully several feet above or below the water surface. Plate I, figure 1, shows a dipper dredge equipped with telescopic bank spuds.

The vertical spuds of various makes are more nearly alike. The rear spud is always of the vertical type and is used to keep the stern of the boat from swinging from side to side as the dredge is operated. The spuds are usually raised and lowered by steel cables connected with the engine. On large machines they are sometimes operated by means of a steam cylinder placed in front of each spud, with a movable clamp or shoe encircling the spud and attached to the piston of the cylinder; this method is, however, wasteful of steam and expensive. Sometimes compressed air is used to aid in releasing the foot of the spud from the mud; less power is thus required to raise the spud. All types of spuds must be equipped with a strong locking device; they must also be so designed that little time is lost in raising or lowering them. A dipper dredge with vertical spuds is illustrated in Plate I, figure 2.

BOOM.

The boom is built either of steel or of wood. In the former case it is made of standard structural sections strongly riveted together. If of wood, it is generally of the "fish-bellied" shape. Some types of long booms are of the open or "knee" build, with a solid filler at the lower end and the chords sprung over posts and cross bulkheads (Plate I, fig. 1). This construction reduces the wind pressure when swinging. Practice has taught that the length of boom must bear a definite relation to the width of the hull. Even on a large dredge it is not advisable to have a boom longer than 80 to 90 feet, although the manufacturers will build them 100 feet long if desired. Large dredges with long booms are much slower in operating than are the smaller-sized dredges. The same number of men are required in either case.

The lower end of the boom is pivoted. The upper and outer end is connected to the yoke at the top of the A-frame by means of adjustable wire cables. A sheave placed at the outer end of the boom carries the cable leading from the dipper through the fair-lead sheaves at the lower end of the boom and thence to the hoisting drum.

On the early type of dipper dredge, chains were used for hoisting and backing. These were hard to install and would break without warning. Steel cable has entirely replaced the old chain since it is less expensive, easier to install, clean, and noiseless; also its weakening, due to wear, is more apparent and accidents are therefore less likely.

DIPPER AND DIPPER HANDLE.

The dipper handle which carries the dipper at its lower end is made either of steel or of wood. On its under side is a cog rack which moves over pinions mounted on the upper side of the boom. It must be made of sufficient stiffness to prevent bending when the dipper is being filled.

On dredges such as are ordinarily used in drainage work, the dipper or bucket varies in size from one-half cubic yard to 4 or 5 cubic yards. The dipper varies considerably in shape with the different manufacturers. For work in ordinary material the cutting edge is made of a single steel plate, preferably of manganese steel, but if the material is hard large steel teeth are used to reinforce the cutting edge. The bottom of the dipper is a heavy steel plate which is hinged to the back and is held in place by a spring latch on the front of the dipper. The latch is operated by the craneman, who thus dumps the contents of the dipper. As the latter is lowered into the ditch the weight of the bottom causes it to close and latch automatically.

The larger the dipper used, the larger must be the engine and boiler, and, in fact, all of the parts, including the hull. Thus the size of a dipper dredge is determined by the capacity of its dipper.

COST.

The cost of dredges advances rapidly as the size and capacity are increased. Dredges of the same rated capacity also vary somewhat in cost with the different manufacturers. All of the machinery is usually made at the shops of the manufacturer. The material for the hulls may also be supplied by the manufacturer, but usually the purchaser obtains lumber in the open market and builds the hull in the field. The cost of hauling the material and machinery from the railroad to the place of erection, the local price of labor, and the conveniences for housing and feeding the workmen are factors which will enter into the cost of a machine of any type. It requires at least two cars to transport the material for a small dipper dredge, while for a machine of large size from four to six cars are required.

The following table gives the approximate costs of the various sizes of dredges ready for operation, though these would be largely affected by the difficulties and expense of transporting the material and assembling the machine:

Approximate costs of dipper dredges.

Size.	Cost of machinery.	Cost of wood hull.	Total.
¾-yard	$3,700	$1,800	$5,500
1-yard	5,400	2,200	7,600
1¼-yard	6,100	2,250	8,350
1½-yard	7,100	4,500	11,600
2½-yard	14,000	9,000	23,000

It requires practically a month for ten men to erect a 1-yard dredge, 6 weeks to erect a 1½-yard or 1¾-yard dredge, and 8 weeks to construct a 2-yard or 2½-yard machine. It requires less than one-half the time given above to dismantle a machine. A 1-yard dredge which cost

DI4421a

FIG. 1.—DREDGE EQUIPPED WITH BANK SPUDS.

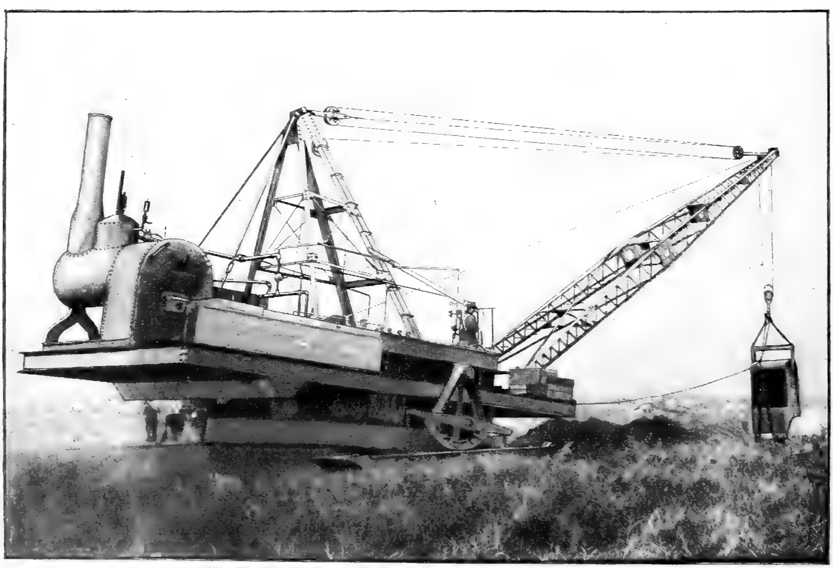
DI4807b

FIG. 2.—DREDGE EQUIPPED WITH VERTICAL SPUDS.

TYPES OF FLOATING DIPPER DREDGES.

D12391

FIG. 1.—MACHINE IN POSITION FOR DIGGING.



D12392

FIG. 2.—MACHINE IN THE ACT OF MOVING.

A WALKING SCRAPER EXCAVATOR OF THE ROTARY TYPE.

$8,000 was shipped about 400 miles and hauled by wagon 18 miles. The dismantling cost about $490; the freight charges were about $700; hauling, $360; and rebuilding about $670. These costs are fairly representative for this size of machine.

METHOD OF OPERATING.

With a floating dredge the construction should, where practicable, begin at the upper end of the ditch and proceed downstream. Sometimes it is not feasible to transport the machinery and material to the upper end of the ditch and the dredge must then work upstream. This is undesirable, unless the fall be slight, since in working upstream dams must be built behind the boat to maintain the necessary water level. In working downstream the ditch remains full and the dredge, floating high, can dig a much narrower bottom than if working upstream in shallow water. Moreover, when floating low, the dipper may not properly clear the spoil bank. Again, in working downstream, any material dropping from the dipper into the ditch will be taken out in the next shovelful; whereas if working upstream any material dropped or any silt washed behind the dredge is left to settle in the bottom of the ditch. If work is begun on the natural ground surface a pit must be dug to launch the boat; or if in a stream, it may be necessary to build a temporary dam in the channel to raise the water high enough to float the boat. The depth of water required varies from 2 feet upward depending on the size of machine.

The floating dipper dredge moves itself ahead by means of the dipper. The spuds are first loosened from their bearings and the dipper is run ahead of the machine and rested on the natural ground surface in front of the ditch. The spuds are then raised and the engines operating the backing drum are started; the dredge, being free, is thus pulled ahead. The spuds are then lowered and excavation continued.

In timbered country the right of way must be cleared. In many cases the timber cut will supply sufficient fuel for the dredge. It is poor policy to fall the trees and leave them on the ground to be removed by the dredge. The stumps should always be shattered with dynamite, as the strain on the machinery is thus rendered much less and the life of the dredge increased.

An engineer, a craneman, a fireman, and a deckhand are required to operate a dipper dredge. The output, loss of time due to breakdowns, and the cost of repairs, depend almost wholly upon their skill and efficiency. The engineer should be an all-around mechanic as well as experienced in dredging.

The amount of fuel consumed depends upon the size and type of boiler used, and upon the burning and heating qualities of the fuel.

A very great saving can be effected by covering the boiler with an asbestos coat. Ordinarily, about 25 pounds of coal per horsepower-hour are consumed on dredges. The cost of repairs depends largely upon the operator; a careless operator will cause many unnecessary breakdowns. It is not only the high cost of repairs for machinery but also the time lost which aids in increasing the actual cost of the output. It is a well-established fact that it is not the initial cost of a dredge or of any machine, but the operating and overhead expenses, that reduce the profits.

COST OF OPERATION.

The cost of dredge work depends upon a number of factors. The locality of the work, the kind of soil, repairs, delays, labor, etc., greatly influence the actual cost of any work. If the water level can naturally be maintained within a foot or so of the surface of the ground, the cost of excavation can be reduced very low with this type of machine. The data given in the following pages were obtained from the actual cost records of the various projects. Unfortunately, the figures are not always strictly comparable, one project with another, owing to variations in the items of cost included. Unless otherwise stated, interest is taken at 6 per cent and depreciation at 35 per cent per annum on the cost of the dredging outfit. Interest and depreciation are, however, charged only for the interval of time upon which the unit cost is based. This is not strictly correct, as a certain amount of time consumed in getting the machine on and off the work should be charged to each project. In most cases it was impossible to ascertain the time that should be charged to moving, building, etc., and therefore the item has been ignored in all cases, for the sake of uniformity. On some projects figures for operation over an extended period were not obtainable. In such cases the unit cost is based upon the daily cost of operation and the average amount of ditch dug per day, no allowance being made for interest and depreciation.

In the construction of a ditch in North Carolina a new 1¼-yard dipper dredge was employed. This dredge had a 5 by 20 by 70 foot hull and was equipped with 8⅜ by 10 inch double-cylinder hoisting engines; 7 by 7 inch double cylinder, reversible swinging engines; a 50-horsepower Scotch marine return-flue boiler; a 1¼-yard dipper, 31-foot dipper handle, and 45-foot boom. The spuds were convertible to bank or vertical and were operated by the hoisting engines. The cost of this dredge, erected, was $10,342.19. The dredge was operated continuously, each shift working 11 hours per day. The men were paid at the following rates per month: Superintendent in charge, $110; engineers, $100; cranemen, $60; firemen, $48; deck-hands, $36. The men furnished their own subsistence. The ditch

was $9\frac{1}{2}$ miles long and ranged from 22 to 30 feet wide on top and from 8 to 10 feet deep; it had side slopes of $\frac{1}{2}$ to 1 and a berm 8 feet wide. The water level was easily maintained near the ground surface. Very little right-of-way clearing was required. In the construction of this ditch the dredge excavated 350,720 cubic yards of earth. One year was required for the dredge to complete this work. The following cost data were taken from the records of the drainage district which owned and operated the dredge:

Cost of operation, including labor and fuel	$15, 889. 01
Repairs	1, 948. 24
Interest and depreciation	4, 240. 22
	22, 077. 47

Cost per cubic yard, $0.0629.

A new dredge of the same size and type as the one just described was used in the excavation of a drainage ditch in the same locality as the foregoing project. The ditch followed an old creek channel for the greater part of its length. The cost of the dredge, erected, was $9,365.34. It was operated in one shift of 11 hours; the actual time of operation was not recorded. The crew and the rates of pay were the same as in the foregoing example. The ditch was $3\frac{3}{4}$ miles long and ranged in top width from 22 to 26 feet and in depth from 6 to 10 feet. The side slopes were $\frac{1}{2}$ to 1; the berm was 8 feet wide. The dredge worked downstream and the water level was easily held near the ground surface. Practically no right-of-way clearing was done. The material excavated was a loam top soil underlain by stiff clay; very little rock was encountered. The cost of the work was considerably affected by the expense ($1,459) of passing three bridges. The total amount excavated in a period of about 10 months was 121,200 cubic yards. The dredge was owned and operated by the drainage district. The following costs were recorded:

Cost of operation, including labor and fuel	$5, 921. 05
Repairs	1, 028. 73
Incidentals	117. 95
Interest and depreciation	3, 199. 80
	10, 267. 53

Cost per cubic yard, $0.0847.

A dipper dredge with a $5\frac{1}{2}$ by 16 by 60 foot hull, 7 by 8 inch double-cylinder hoisting engines, friction swing, 1-yard dipper, 35-foot boom, and telescopic bank spuds was used in the construction of about 5 miles of ditch in western North Carolina. No reliable information was available as to the amount of material moved; but the following figures as to the cost of installing the dredge are of interest:

Hull: Labor and material	$1,803.23
Machinery:	
Material	4,800.00
Freight	379.10
Drayage	72.60
Installing	310.60
Extra equipment (forge tools, etc.)	80.00
Lighting equipment (engine and dynamo and wiring)	207.00
	7,652.53

In Colorado, a dipper dredge having a 24 by 75 foot hull, 1½-yard dipper, and 50-foot boom, was used in cleaning out and enlarging about 20 miles of canal. The equipment, complete, including cook and bunk boats, cost $16,500. Two shifts of 11 hours each were run. During the year for which the data are given the dredge was actually in operation but 187 days, or 58 per cent of the total working days. The following crew were paid the given rates per month, including board: Head runner, $120; 1 runner, $110; 2 cranemen at $55; 2 firemen at $45; 2 deckhands at $40; 1 teamster, $40; 1 cook, $50. No right-of-way clearing was required. The water for the boiler was taken from the canal, and as a result considerable trouble was experienced from mud and scale. The cost data below are based on the amount of material moved from inside the grade stakes during the year, amounting to 394,387 cubic yards. It was estimated that an excess of 25 per cent was actually moved. The following was the cost of the work for one year:

Operation:	
Labor operating dredge	$6,243.70
Coal, including freight, 1,276.65 tons, at $2.35	3,000.13
Hauling coal, 1,276.65 tons, at 82½ cents	1,053.24
Oil, waste, and miscellaneous supplies	692.80
Cost of controlling water to float dredge	369.24
Repairs, labor, and material	3,894.67
Removing and replacing bridges	837.78
Interest and depreciation	6,765.00
	22,856.56
Cost per cubic yard, $0.058.	
Miscellaneous expenses:	
Engineering and supervision	$1,856.10
Building up ditch bank and making road on top	4,721.75
Right of way and legal expenses	190.42
	6,768.27

The cost of the dredging outfit was as follows:

Hull:	
Material	$1,960.83
Labor, including hauling	1,959.99
Machinery:	
Cost, including freight	9,997.72
Hauling and installing	817.55

Cook and bunk boats:

Material	$663.90
Labor	453.66
Equipment	646.35
Total	16,500.00

In connection with a drainage project in southwest Louisiana a steam-operated, floating dipper dredge, equipped with a 1-yard dipper, 40-foot boom, and convertible power spuds was employed in the excavation of about 10 miles of ditch which varied in width from 18 to 50 feet and in depth from 4 to 6 feet; 15-foot berms were specified. The cost of the dredge on the work is said to have been $10,000. Two shifts of 10 hours each were run, but the actual number of days of operation was not recorded. The crew and monthly rates of pay, including subsistence, were as follows: Two runners, at $100; 2 cranemen, at $60; 2 firemen, at $60; 1 deckhand, $40; 1 cook, $30, The material excavated was a hard, stiff clay. The total amount excavated in about 8 months was 147,000 cubic yards. The average cost, per month, of operation was as follows:

Labor	$510
Board	100
Coal	262
Repairs	200
Oil and supplies	50
Interest and depreciation	342
	1,464

Cost per cubic yard, $0.0796.

On another project in southern Louisiana there was employed a floating dipper dredge with a 5 by 22 by 73 foot hull; 8 by 10 inch double-cylinder hoisting engine; 6 by 8 inch, double-cylinder reversible swinging engines; $1\frac{1}{4}$-yard dipper, and 40-foot boom. The machine was equipped with bank spuds. The cost of the dredge, ready to operate, was $13,000. The ditches averaged about 30 feet wide and were from 5 to 6 feet deep. The land was nearly level and the water surface was easily kept within a foot of the ground surface. The material was a top muck underlain by an alluvial mud which was hardly solid enough to hold its shape when dropped from the dipper. There were few submerged logs or stumps. The dredge was operated the year around for 2 years. No record was kept of the actual time of operation. The average output per shift (12 hours) on a 30-foot ditch 5 feet deep was 1,200 cubic yards, at a cost as follows:

Labor (4 men)	$10.50
Fuel, 6 barrels oil, at $1.75	10.50
Repairs, oil, and grease	5.50
	26.50

Cost per cubic yard, exclusive of interest and depreciation, $0.0221.

In the same general locality as the foregoing case, and under the same soil conditions, a 1-yard dredge which was, except in respect to capacity, equipped similarly to the above-described machine, was operated in the construction of ditches which averaged 30 feet wide and 5 feet deep. The cost of the dredge, erected, was $11,000. The average output per 12-hour shift during a 2-years' run was 1,000 cubic yards. The cost per shift was as follows:

Labor (4 men)	$10.00
Fuel, 5 barrels oil, at $1.75	8.75
Repairs, oil, and grease	5.50
	24.25

Cost per cubic yard, exclusive of interest and depreciation, $0.0242.

In another drainage project in southern Louisiana several ditches, each 3 miles long, were constructed by a dipper dredge installed on a 5½ by 18 by 70 foot hull. The power was obtained from a 60-horsepower internal-combustion engine. The dredge had a 1¼-yard dipper, 40-foot boom, and convertible power spuds. The total cost of the outfit, including house-boats and small towboats, was $12,000. Two shifts of 10 hours each were run for 26 days in each month. The crew were furnished subsistence, and each shift consisted of: One runner, at $125; 1 craneman, at $65; and 1 engine tender, at $40 per month. One cook, at $35, and one general utility man, at $60, were also employed, making a total labor cost of $555 per month. The average dimensions of the ditch were: Top width, 25 feet; bottom width, 18 feet; and depth, 8 feet. The ground was nearly level and the water stood about 3 feet below the ground surface. The excavated material was a stiff, sandy clay. About 3.4 miles of the work consisted in cleaning old channel, which required frequent moving and gave small yardage. The total excavation in five months was about 216,000 cubic yards. The cost was as follows:

Labor and board	$3,555
Fuel and oil	2,300
Repairs	980
Interest and depreciation	2,050
	8,885

Cost per cubic yard, $0.411.

A steam-operated floating dipper dredge, mounted on a 5 by 15 by 60 foot hull and equipped with a 1-yard dipper, 38-foot boom, and inclined telescopic bank spuds, was used in the excavation of about 10¾ miles of ditch in North Carolina. The cost of the dredge is stated to have been $6,613.82. One shift of 10 hours per day was run. The actual number of days of operation was not recorded. The crew and rates of pay were as follows: One engineer, $125 per month; 1 craneman, $2 per day; 1 fireman, $1.25 per day; 1 watchman, $1.50 per day. The crew furnished their own subsistence.

The ditch was about 18 feet in top width, 12 feet deep, and had $\frac{1}{2}$ to 1 slopes. It followed an old creek bed for a large part of the distance. The material excavated was a clay, though some rock was also encountered. Based upon the given dimensions of the ditch, the total excavation amounted to 295,000 cubic yards. Eighteen months were required to complete the work. The cost was as follows:

Operation:	
Labor	$6,310.94
Fuel	2,210.30
Repairs:	
Labor	1,380.12
Material	1,136.71
Interest and depreciation	4,067.00
	15,105.07

Cost per cubic yard, $0.0512.

Miscellaneous expenses:	
Engineering	$164.83
Clearing right of way	282.70
Rebuilding bridges	104.96
Incidentals	48.77
Administration	618.00
	1,219.26

SELECTION OF DREDGE.

The floating dipper dredge is admirably adapted to the excavation of drainage ditches having sufficient width and depth and the necessary supply of water for floating the machine, and especially where the ground is swampy or covered with trees or stumps, rendering impracticable the use of teams or of so-called dry-land machinery. No other type of excavator is so well fitted for digging ditches in a timbered country or where large stumps will be encountered. The dipper dredge, however, is not well adapted to digging channels of less than 100 square feet cross section. Standard types of dipper dredges are not adapted to digging ditches more than 1,200 square feet in cross section, although most makers will build special machines for larger ditches. As ordinarily operated, the dipper dredge constructs a more or less ragged and irregular ditch, but in the hands of a skilled operator very good results can be obtained.

The size of dredge that should be used depends upon various factors. Not only the greatest and least, but also the intermediate cross-sectional dimensions of the proposed ditch should be known, and the relative amount of each class. The specified width of berm and the side slopes should also be known. The total amount of excavation, the nature of the material, and whether the dirt is to be dumped on one or both sides, are factors that must be considered. A knowledge of the depth of water which can be maintained at a minimum expense is also necessary, and information as to the num-

ber and size of stumps to be encountered is of the highest importance. Owing to the expense of knocking down, transporting, and setting up a dredge, it is necessary to select or use one of the size that will do the most work at one building. This requires an intimate knowledge of the layout of the proposed work, and of the accessibility of the different portions.

It is the opinion of many contractors that the use of dredges with narrow hulls, say less than 18 feet, is to be avoided except where the ground is so hard that the bank spuds rest firmly and bear the weight of the swinging load; in soft ground it may be cheaper to use a wider hull, even though it be necessary to make the ditch wider than is specified.

The various makers of dredges have compiled and made available to prospective purchasers tables, giving full descriptions of their machines. These tables give for each of the numerous dipper capacities such data as the following: Length of boom and dipper handle; distances machines will dig below water line and dump above water line; distance from center of hull to center of dump; dimensions of hull and amount of lumber required to build; sizes of hoisting and swinging engines; and daily digging capacity of machine. With the aid of these data, and having in mind the ditch specifications and the factors enumerated in the preceding paragraph, the proper size of dredge for a particular ditch may be determined.

Where it will be necessary to cope with stumps, this factor will often be the ruling one in determining the capacity of machine needed.

When designing a ditch, the engineer should always have in mind the type and size of machine to which the work is adapted. So far as is consistent with other considerations a ditch system should be so designed as to give the contractor the greatest amount of excavation for a given size of dredge. This point can best be illustrated by a practical example. A certain ditch was designed with a bottom width varying from 16 to 46 feet, and with a cut of about 7 feet throughout the entire length of 15 miles. The ditch as planned was too wide at its lower end to be constructed by an ordinary-sized dredge, unless equipped with the telescopic or the convertible power spuds. By making the cut deeper at the lower end, the width of the ditch could have been made considerably less and an ordinary dredge could have dug the ditch throughout. The necessity of using two dredges of different sizes on such a comparatively small job of course tended to increase the unit cost of the work. Conditions may, it is true, be such as to make a deeper ditch impracticable, as, for instance, scour due to too great a velocity, the lack of a free outlet, the presence of rock, and other conditions.

In planning drainage for a small area which can be drained by one dredged ditch from 6 to about 12 miles in length, the engineer will frequently make the above-mentioned mistake of designing his ditch too wide at the outlet. On large projects, where the amount of excavation is great, this condition will not occur so often, since there is usually sufficient yardage to warrant the installation of two or more plants. The engineer should remember that if the ditches are so planned that one machine can do all the work, even though the yardage is sufficient to justify two dredges, the cost of construction will be reduced. However, the time required to do the work with one machine may be so great that the district would rather pay the additional cost involved in installing two plants.

A contract may consist of a number of ditches all but one of which are suited to a given size of machine. This ditch is too wide to be cut by the dredge at one cutting, and the yardage is insufficient to justify the installation of another dredge. The difficulty may be overcome by making a double cut. This, however, requires the use of either vertical or the convertible type of spuds.

If the best prices are to be obtained, each 1½-yard dredge on a project should have a minimum of 250,000 cubic yards and each 3-yard dredge not less than 500,000 cubic yards.

THE FLOATING GRAB-BUCKET DREDGE.

In construction the floating grab-bucket dredge differs from the dipper type only in the appliances for handling the material. Instead of using a dipper and dipper handle, an orange-peel or a clamshell bucket is suspended from the end of the boom. The bucket of the orange-peel type is the one more generally used for drainage work.

A much longer boom can be used with the grab-bucket dredge than with the dipper dredge. From 75 to 85 feet is about the maximum length of boom that can be successfully operated on a dipper dredge, while booms as long as 240 feet have been used on grab-bucket dredges. This feature is of especial importance in levee construction, as it is desired to deposit the material as far from the stream as possible.

While the dipper dredge pulls itself ahead by means of the dipper, with a grab-bucket dredge some type of "pull-ahead" line is necessary. Generally three auxiliary drums are provided, which are used for operating the two spuds and for overhauling the pull-ahead line, which is securely fastened to the bucket. The bucket is dropped into the material, the hoisting line is slackened, and the pull-ahead line is drawn taut, thus pulling the dredge ahead. In other cases the pull-ahead line may be anchored to a "dead man" buried some distance ahead of the machine.

Owing to its long reach, the grab-bucket dredge is often used for levee construction. It, however, is not very extensively used for the excavation of drainage channels, although there are certain conditions under which it can be used to greater advantage than can the dipper dredge. It excels in handling the muck found on the prairie lands of southern Louisiana and in certain other localities, and under such conditions is better adapted to ditch and levee construction than is the dipper type. The latter, however, is preferable for digging hard soil and stumps.

THE DRAG-LINE SCRAPER EXCAVATOR.

The drag-line scraper excavator is a type of dry-land machine that has come into prominence only within the last few years. It has made feasible the cheap construction of much larger ditches and levees than is possible by the use of any other type of machine.

In the type most commonly used, the engine platform, engine house, and boom are connected and revolve on a turntable which is secured to a lower platform built up of structural steel sections. This is known as the revolving or rotary type and is illustrated in Plate II. Upon the upper surface of the lower platform is riveted the track upon which the swinging circle revolves, and in its center is the pivot bearing. The turntable is a steel-frame circle supported by several wheels which rest upon the track. The upper platform, which is also built up of standard steel sections, is held to the lower platform by means of a central pivot.

In the stationary type the engine platform is fixed; the boom is pivoted at its lower end and is the only part of the machine which swings. This type is illustrated in Plate IV, figure 2.

The power equipment of the drag-line excavator may be either steam, gasoline, or electric. Unlike the floating dipper dredge, the internal combustion engine has been used with success on drag-line excavators and meets with favor among contractors. For the steam plant the boiler most commonly used is either the locomotive or the Scotch marine return-flue type. On the smaller machines vertical boilers are sometimes employed. The engines used consist of two sets, the main engines and the swinging engines. The former are set in front and are of the horizontal double-cylinder type, with engines and drums self-contained on a single cast-iron or steel bed plate.

Sometimes the swinging is done by a mechanism attached to the main engine. Ordinarily, however, separate swinging engines are provided. In the rotary type these engines drive, through a series of gears, a pinion which engages the circular rack on the lower frame. Where electricity can be secured cheaply the machines can be operated very economically by this power.

In the smaller drag-line machines the boom is generally constructed of two channels with cross bracing, while for the larger machines two cross-braced lattice girders are used. The lower ends of the two main members of the boom are spread apart to give stability, while at the upper end the two members are joined, at which point one or more sheaves are placed. The top of the boom is guyed to the top of the A frame which is located near the front of the main engine. The lower ends of the A frame are bolted to the platform while the upper end is guyed to the rear corners of the platform.

The bucket most frequently used on drag-line excavators is of the scraper type, although the clam-shell and orange-peel buckets are sometimes used for special work. The scraper bucket is connected to the main engine by two steel cables called respectively the hoisting and drag-line cables. The bucket is filled by being pulled toward the machine, and when full is raised by the hoisting cable which passes from the bucket over the sheaves in the end of the boom and down to the hoisting drum. There are many patented devices for quickly dumping the bucket, a feature that is important in digging sticky material. The capacity of the scraper buckets range from about five-eighths cubic yard to 3 cubic yards.

The crew necessary to operate this type of machine consists of two men, an operator and a fireman on the steam machine, or an operator and an oiler on the gasoline or electrically-driven machines. In addition to these, two or more trackmen are required, except in the case of the so-called walking type.

For movement over the ground the drag-line excavator may be mounted on either wheels, rollers, caterpillar tractors, trucks, or walking shoes.

Where the ground is uneven or cut up with old channels and surface ditches, it is necessary in the case of all traction or roller excavators which are not of the rotary type to block or bridge across the depressions and to lay heavy timbers on which to move the machine. Where the machine weighs 25 tons or more the expense of providing a solid foundation becomes quite great. In the rotary type of excavator the machine can be revolved and can build its own foundation of earth.

Drag-line excavators vary greatly in weight, not only with the capacity of the machine but with the manufacturer. Some of the five-eighths-yard stationary types weigh no more than 12 tons. There are a few standard makes of drag-line excavators which, although they may differ in details of construction, are operated in the same manner. They vary in weight from 25 tons to about 110 tons. It is especially noteworthy that in all makes the heavier machines are mounted on wooden rollers or on trucks to run on a track. Wheels and caterpillar traction are used only on the lighter

machines. Although caterpillar tractors require no track, they have not given complete satisfaction when working under all the different conditions usually met with in operation. The wear on the chains is very great in sandy soil, and the expense of repairs and the time lost through breakdowns are likely to be considerable.

VARIATIONS IN ROTARY TYPE.

For the purpose of eliminating some of the weaknesses in the ordinary moving devices a novel design of walking scraper excavator of the rotary type has been put on the market. (See Pl. II.) Attached to the upper platform and extending through the machine in a direction at right angles to that of the boom is a heavy steel shaft, on each end of which is a wheel segment. The shaft also carries a large gear wheel, which meshes with a pinion on the loading-drum shaft of the main engine. Suspended from the middle arm of each segment by means of a carrying beam and chains is a long shoe which affords a bearing for the segment as it rotates and propels the machine forward. The machine can be made to move in any desired direction by first swinging the upper platform. The excavator is moved ahead 8 feet during each complete revolution of the segment. The great advantage of this type of machine, as well as of the excavator mounted on caterpillar tractors, is the reduction in the necessary working force from four to two men, the trackmen being unnecessary. It is claimed that five men can take this type of machine down in a week and erect it in about two weeks. The machine weighs about 60 tons and costs $7,000. Three cars are required for shipping it.

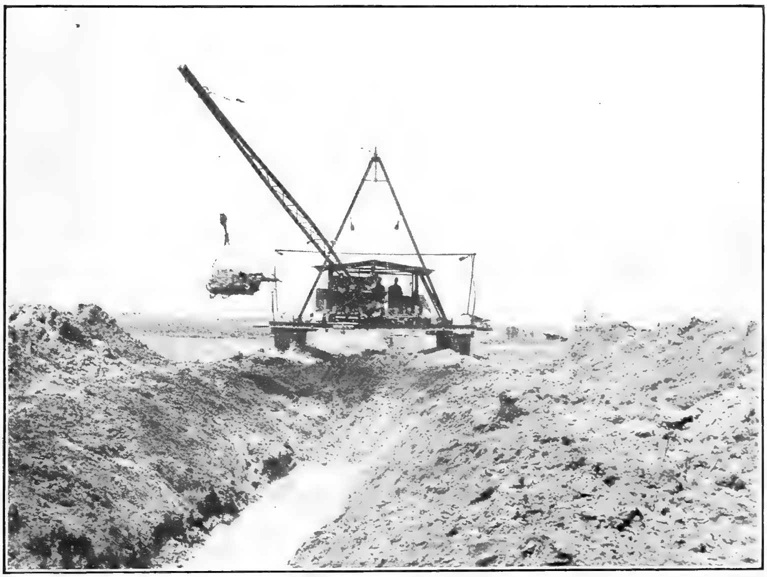
Another form of the rotary type is the so-called boom-guided bucket excavator. The entire machine rests on two steel rails spaced 12 feet apart and laid on short wooden ties. Either steam or gasoline may be used as power. The unique feature of this machine is the boom on which the scraper bucket travels. (Pl. III, fig. 1.) It is the purpose of this guide boom to overcome the difficulty of holding the ordinary bucket in place in passing from stiff to loose material.

The bucket, which is a rectangular steel box open at the end toward the machine, travels upon the guide boom on steel rollers. To fill, the bucket is first pulled outward by the back-haul cable, which leads from the bucket to the head of the main boom and back to the engine. The guide boom is then lowered and the bucket pulled toward the machine. The bucket is dumped by being pulled up on the vertical end of the guide boom, the boom having first been swung around to the location at which the material is to be deposited.

This machine is made with three different lengths of boom, a 30-foot adjustable boom which can be increased to 40 feet, a 40-foot, and a 65-foot boom. Buckets of $1\frac{1}{3}$, $1\frac{1}{2}$, and 2 cubic yards are used on these machines. It is claimed that 5 men can take down the

D14118a

FIG. 1.—BUCKET AND GUIDE OF THE BOOM-GUIDED BUCKET EXCAVATOR.



D12393

FIG. 2.—A LIGHT STEEL SCRAPER EXCAVATOR MOUNTED UPON WHEELS.

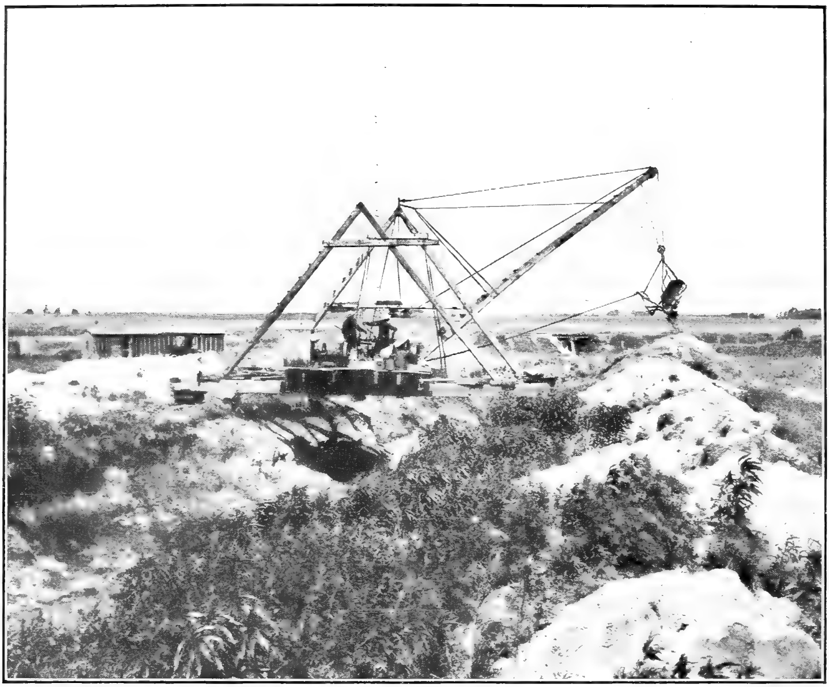


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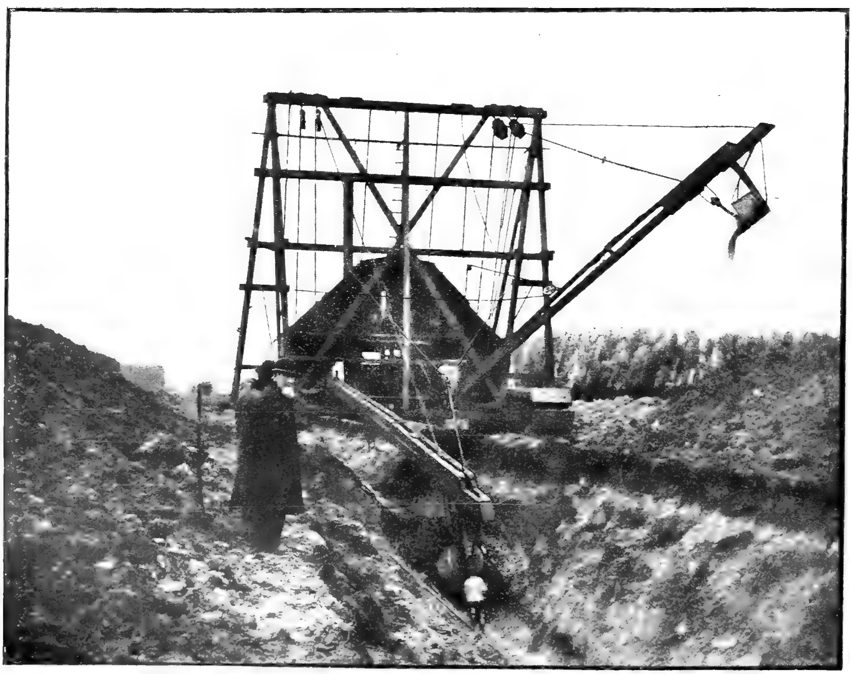
FIG. 1.—A LIGHT WOODEN SCRAPER EXCAVATOR CLEANING A DITCH.

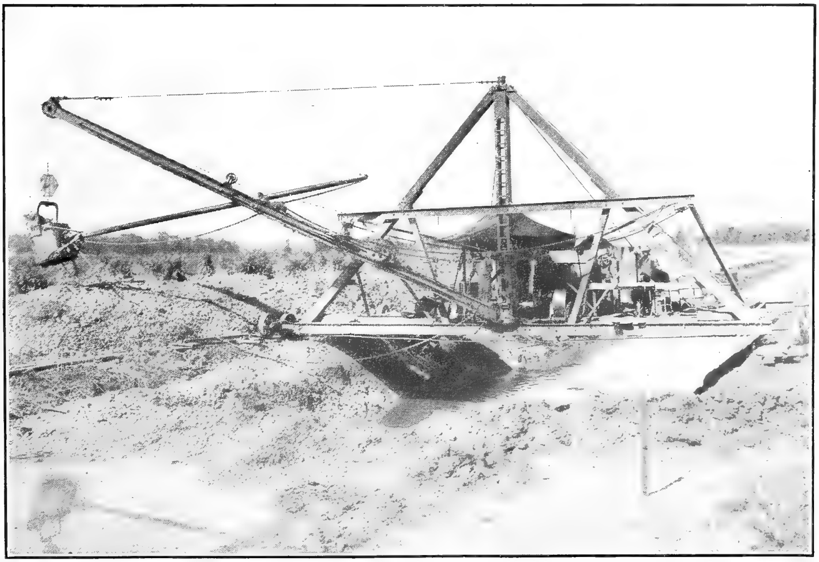


D12394

FIG. 2.—A SCRAPER EXCAVATOR WITH TWO BUCKETS AND MOUNTED UPON RUNNERS.

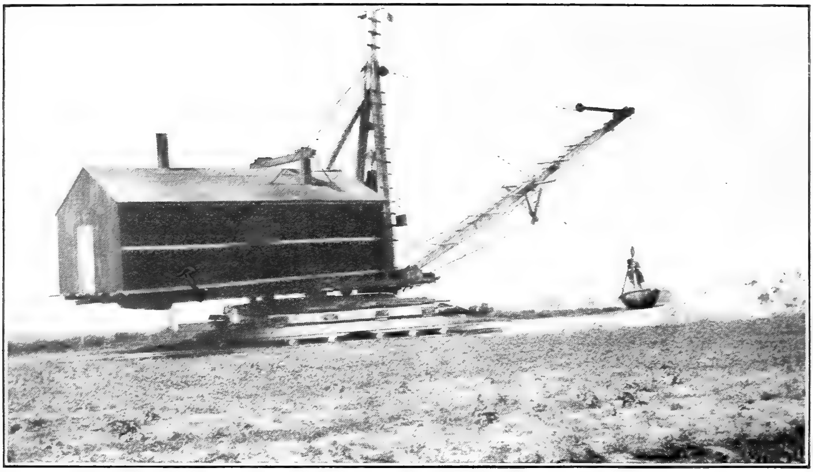
D12395

FIG. 1.—A 1-YARD DRY-LAND DIPPER EXCAVATOR MOUNTED UPON CATERPILLAR TRACTORS.



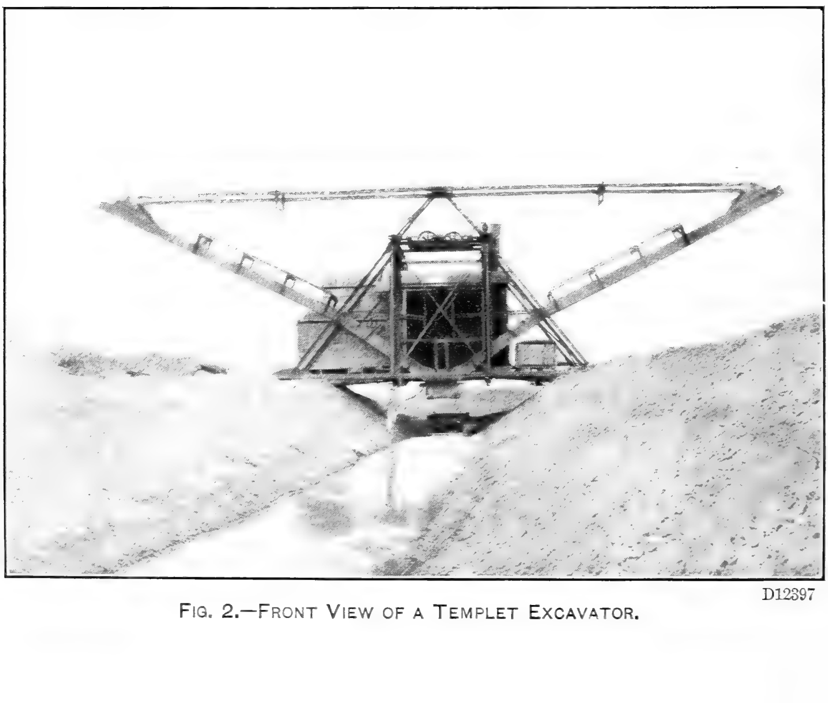
D12396

FIG. 2.—A 1-YARD DRY-LAND DIPPER EXCAVATOR MOUNTED UPON TRUCKS.



PR4177a

FIG. 1.—A DRY-LAND ORANGE-PEEL EXCAVATOR.



D12397

FIG. 2.—FRONT VIEW OF A TEMPLET EXCAVATOR.

machine of the smaller size in from 2 to 3 days and easily put it up in a week. It makes 13 loads on a wagon and can easily be loaded on a flat car.

COST OF ROTARY TYPE.

The cost of revolving drag-line excavators runs from about $6,000 to about $25,000. A steam-operated excavator equipped with a 40-foot boom and a 1¼-yard bucket costs about $6,500 if mounted on skids and rollers, and $10,000 if mounted on caterpillar traction. A steam-operated excavator equipped with a 60-foot boom and 2-yard bucket costs $9,000 if mounted on skids and rollers, and about $13,000 if mounted on caterpillar traction. If operated by internal combustion engines, this last-named machine would cost about $17,000. A steam excavator with a 125-foot boom costs approximately $27,000.

VARIATIONS IN STATIONARY TYPE.

A number of different forms of the stationary type of drag-line excavator are on the market. A light machine of this type has been put out recently which is being used quite extensively (Plate III, fig. 2). The machine is built entirely of steel. The main frame is 24 by 24 feet and can easily be made wider or narrower if desired. The platform is 12 by 30 feet. The frame is mounted on four steel wheels, each 5 feet high and 2 feet wide. The boom is 40 feet long and can be extended an additional 10 feet if it is desired to use the machine for tile trenching or lowering large tile into place. A 40-horsepower, 4-cycle gasoline engine is used for power. The bucket has a capacity of five-eighths cubic yard. The machine complete weighs 12 tons. When dismantled it can be loaded on one flat car, or if transported by team will make 7 wagon loads. One man is required to operate the machine and one man to handle the track in soft ground. From 20 to 25 gallons of gasoline are required per 10-hour day. The machine can be moved ahead without interrupting its operation by means of a cable attached to a "dead man" or to stakes. The large wheels will travel over reasonably firm ground without track and no trackman is therefore needed except in extremely soft ground or swamp. The machine costs approximately $4,500.

This same type of machine, made entirely of wood, is convenient for light work such as cleaning ditches, etc. Such a machine is illustrated in Plate IV, figure 1. It is equipped with two 12-horsepower, air-cooled gasoline engines, 50-foot boom, and ½ cubic yard bucket, and has been used in cleaning out old ditches in Iowa. The machine weighs about 12 tons and cost $3,000. Four men are required in using it, two operators and two trackmen. About 20 gallons of gasoline are required per 10-hour day. Four men can set such a machine up in 3 days and can take it down in 2 days. The

maximum width of ditch a machine of the above size can dig is 50 feet and the greatest depth is 22 feet. It has excavated 500 cubic yards in 10 hours. The machine is supported on 4 wheels, and is moved on the work in advance of the excavation by cable and "dead man."

Another drag-line machine of the stationary type has been designed to meet the demand for a light excavator that can be economically and quickly moved across country from one job to another. The power consists simply of a steam or oil traction engine which forms the rear of the machine as shown in figure 1. The front end is carried on two wide wheels. It is claimed that this excavator can be moved over ordinary country roads, or even across fields, at the speed of an ordinary large traction engine, and that it can be quickly taken apart and reassembled if shipment is desired. For work on soft ground a heavy timber pad is provided for each wheel. These are shifted by engine

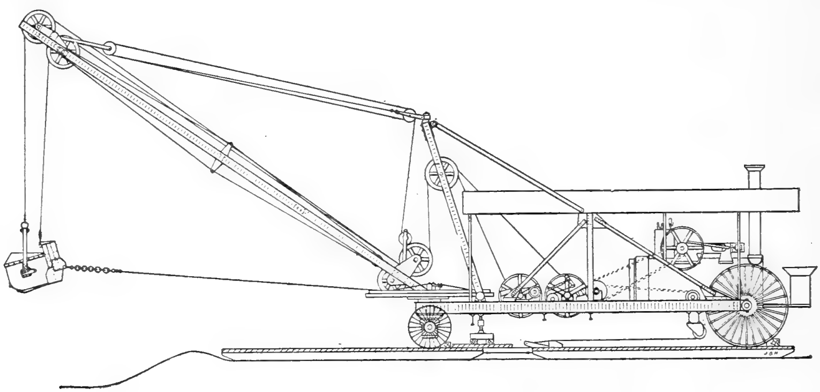


FIG. 1.—Drag-line scraper excavator of the stationary type.

power; in doing this one side of the machine at a time is raised on power jacks.

A drag-line machine with two buckets has been used to some extent in the excavation of drainage channels. This machine, illustrated in Plate IV, figure 2, is mounted either on runners or on caterpillar tractors. The two booms, which are separated at the foot according to the width of the ditch to be cut, swing from the center of the ditch outward. The operations are so timed that one bucket is being emptied while the other is being filled. This feature greatly increases the output of the machine. The excavator can be dismantled for shipping in about 2 weeks and can be assembled in about 1 month by a crew of 5 men. Under favorable conditions this machine has excavated 1,500 cubic yards in 15 hours. Such a machine, equipped with 42-foot booms, can dig a ditch with a 46-foot top, 25-foot bottom, and 12-foot depth.

COST OF OPERATION.

A drag-line excavator of the rotary type, having a 2-yard scraper bucket and a 60-foot boom, was used in the construction of some drainage ditches in southern Texas. It was built mostly of wood and moved on rollers. Power was derived from an 80-horsepower internal-combustion engine, burning oil. The cost of the excavator, ready to operate, was $12,000. It was operated about 10 months in two daily shifts of 10 hours each, a shift consisting of 10 men. The actual working time was not recorded. The ditch ranged from 4 to 22 feet in bottom width, from 3 to 12 feet in depth, and had 1 to 1 side slopes. The soil varied from a stiff, heavy clay to a fine sand. The excavation amounted to 230,000 cubic yards; the cost was as follows:

Operating expenses	$22, 313. 36
Miscellaneous expenses	374. 70
Interest and depreciation	4, 100. 00
	26, 788. 06

Cost per cubic yard, $0.1164.

On another drainage project in southern Texas, a 2-yard rotary excavator was used. The machine was of steel throughout, had a 60-foot boom, and was mounted on caterpillar traction. The crew consisted of a foreman, operator, engineman, oiler, and two laborers. The machine was operated by a 110-horsepower internal-combustion engine, with oil as fuel. The total cost of the machine was about $17,500. The cost of erection was $509. During the four months of operation two 10-hour shifts were run. The ditches ranged from 4 to 22 feet in bottom width and from 3 to 12 feet in depth, with 1 to 1 side slopes and 8-foot berms. The material excavated was a stiff, heavy clay. The excavation amounted to 91,400 cubic yards; the cost was as follows:

Operating expenses	$8, 873. 82
Miscellaneous	371. 00
Interest and depreciation	2, 391. 00
	11, 635. 82

Cost per cubic yard, $0.1273.

In the same general locality as the last example a 1½-yard rotary drag-line excavator, operated by a 50-horsepower internal-combustion engine and mounted on caterpillar traction, was used in the construction of some ditches in soil ranging from stiff, heavy clay to fine sand. The ditches were of the same dimensions as in the foregoing example. The machine was rebuilt from an old dipper dredge at a cost of about $1,200. It was operated in two daily shifts of 10 hours each. The crew for each shift consisted of from 5 to 6 men. During the five months of operation the machine moved 59,014 cubic yards at an expense, exclusive of interest and depreciation, of $8,921, or $0.1512 per cubic yard.

A rotary drag-line excavator with a $2\frac{1}{4}$-yard bucket and 65-foot boom, mounted on skids and rollers, was used in the excavation of 222,500 cubic yards in South Dakota. The power was obtained from a 50-horsepower internal-combustion engine, using gasoline. The cost of the machine, complete, was $10,500. The total time of construction was 148 working days, or approximately 6 months, of which 23 days were occupied in making repairs. Two shifts of 11 hours each were run. The soil was a loam underlain by clay. The crew and rates per month were as follows: One superintendent, $125; 2 cranemen, at $100; 4 trackmen, at $50; 1 teamster, $45; 1 cook, $40. The operating expenses were as follows:

Gasoline, 15,444 gallons, at $0.124	$1,915.05
Labor	3,060.00
Subsistence	561.81
Cables	978.87
Repairs and renewals	845.93
Miscellaneous	2,078.72
Interest and depreciation	2,152.50
	11,592.88

Cost per cubic yard, $0.0521.

The following costs were secured on the operation of a rotary drag-line excavator with an 85-foot boom, 2-yard bucket, and a 50-horsepower engine. The work was done on the New York State Barge Canal. The machine weighed 147 tons and cost $10,000. It excavated earth 90 feet from center on one side and deposited it 100 feet from center on the other. It dug a channel 25 feet deep and deposited the material on waste bank 15 to 25 feet high. The material was a stiff clay, with few stumps or bowlders. The following is a condensed cost record for 5 months' work:

Month.	Total expense for month.	Yards excavated during month.	Average cost per yard.
April	$1,088.21	5,205	$0.209
May	1,041.53	18,365	.0568
June	1,152.04	25,333	.0455
July	1,317.61	33,055	.0399
August	1,535.36	47,363	.0324

Average cost per yard for 5 months, including all charges, $0.0474.

In May, items of cost were as follows:

Engineer, at $90 per month	$90.00
Engineer, at $95 per month	84.04
Fireman, pumpmen, watchmen, etc., at $1.75 per day	363.00
Coal, at $3 per ton	147.00
Repairs, including labor and material	15.82
Interest and depreciation	341.67
Total	1,041.53

SELECTION OF SCRAPER EXCAVATOR.

In selecting a scraper excavator the purchaser, in addition to choosing the most desirable kind of power and the best means of moving over the ground in his particular case, must determine the length of boom best suited to his needs.

Figure 2 is a diagram showing the relation between the length and angle of elevation of boom and the effective reach of machine. In this diagram all distances are referred to the heel of the boom. If it is desired to refer horizontal distances to the center of the machine, the correction A must of course be added; this distance varies with the different makes of machine. The distance, B, of the heel of the boom above the ground, likewise varies slightly in different machines.

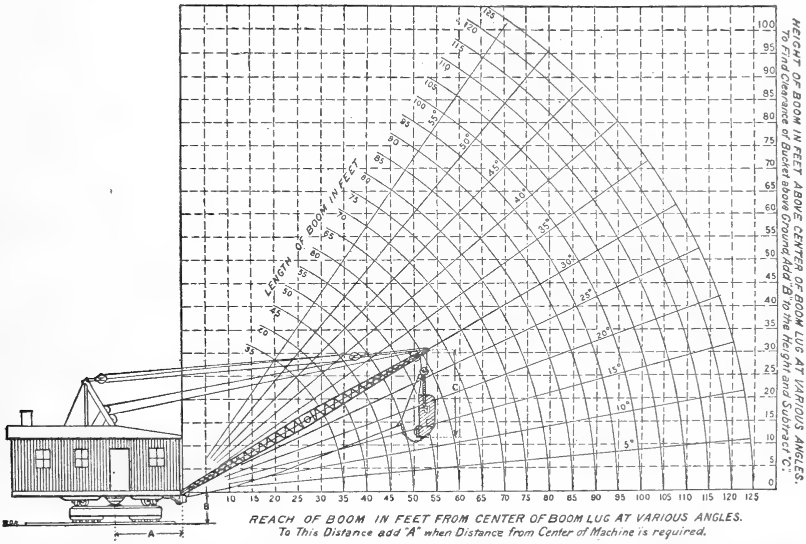


FIG. 2.—Diagram of scraper excavator, showing relation between the length and elevation of boom and the effective reach of machine.

To determine the maximum clearance of the bucket above the ground for different lengths and positions of boom, the distance B must be added to the vertical heights given on the right-hand margin of the diagram; and from this sum must be subtracted the distance C, which will depend entirely upon the type of bucket used. Thus, for a 70-foot boom elevated at an angle of 35°, the horizontal distance from the center of machine to the bucket would be 57 + A; and at that position of the boom the bucket would just clear a waste bank of a height 40 + B − C.

THE DRY-LAND DIPPER EXCAVATOR.

Excavating machines employing the same digging principle as used on the floating dipper dredge, but moving on land, either over or in

the ditch, are used to a considerable extent in drainage work. A common form of this type straddles the ditch on cross-beams. The straddle ditchers generally work upstream as do all dry-land excavators.

A machine of this type often used is illustrated in Plate V, figure 1. It has a 30-foot boom and a 1-yard dipper. The steam power used is obtained through a 2-cylinder, 35-horsepower engine and a vertical boiler. The machine rests on a platform which is mounted on two steel beams, each 29 feet long, that straddle the ditch. It can be mounted on either caterpillar tractors or wheeled trucks. In the latter case, each end of the two beams is supported on a 2-wheeled oscillating truck, the wheels being 2 feet high and 18 inches wide. They run on a wooden track 6 inches thick and 3 feet wide, which is built in 6 sections each 20 feet long. One section of the track on each side is always unoccupied and these are lifted ahead by means of cranes operated by power derived from the engines. This track will support the machine in the softest ground. The excavator will dig 12 feet deep and 22 feet wide on firm ground; with an extension to the dipper handle it can dig 18 feet deep. It will deposit the dirt on either side at a distance of 32 feet from the center of the ditch. The dipper will swing over a bank 14 feet high. Where track is used the machine is pulled ahead by a cable from the engine which hooks to the track on both sides; this is done without interrupting the work of excavating. If desired, caterpillar tractors are furnished instead of the wheeled trucks. The front tractors are 4 feet wide by 11 feet long, and the rear tractors are 4 feet wide by 7½ feet long. This excavator has been known to dig as high as 1,500 cubic yards in 10 hours in especially favorable material. It has dug through 12 inches of frost. From 7 to 8 men can set up and take down the machine in from 5 to 8 days.

Another machine of this type is illustrated in Plate V, figure 2. The excavator is made in various sizes; that most commonly used has a 38-foot boom and a 1-yard dipper. Power is supplied by an internal-combustion engine of 25 or 40 horsepower which burns kerosene, gasoline, or distillate oil. The machine rests on a platform which is mounted on two steel beams, whose standard span is 32 feet. Extension axles are provided which permit of a maximum increase of 3 feet in the span. The front axle is mounted on a two-wheeled swiveling truck with cast-steel double-flange wheels. The rear end is carried by two heavy, wide-faced, double-flange steel wheels set loosely on the axle. The shipping weight of this size of dredge, including engine, dipper, and machinery, is approximately 38,000 pounds.

Perhaps the cheapest straddle-ditch excavator of the dipper type that is in use is a homemade one which has been used to some extent

on small ditches in Iowa. The machine is of the revolving type. It is equipped with a three-fourths-yard dipper and a 28-foot boom. The power is derived from a 6-horsepower gasoline hoisting engine geared to three hoisting drums, one of which hoists the end of the dipper, one hoists the boom, and one pulls the machine ahead. The machinery is mounted on a platform which revolves upon a turntable supported on two wooden beams which straddle the ditch. The beams rest on wooden wheels, the entire span being 22 feet. The dipper handle, instead of moving forward and backward in the boom, is pivoted. The entire machine weighs only about 17,000 pounds and costs about $1,200.

This excavator has dug as high as 400 cubic yards a day, but averages about 200 cubic yards. It can excavate a ditch with a 20-foot top and can dig 13 feet deep, but 6 or 7 feet is the best working depth. Two men can erect the machine in 2½ days and dismantle it in one-half day; it makes about 7 wagon loads. The hoisting apparatus, which is the heaviest part of the machine, weighs 4,100 pounds. The excavator is moved ahead by means of a "dead man" and cable, and can be moved across country at a speed of about 1 mile per day. The machine can take out 5 shovel-loads in 2 minutes, and has dug through 6 inches of frost. Only 2 men are required to operate it—1 operator and 1 trackman.

A ditch constructed by this machine in Iowa had an 18-foot top, 4-foot bottom, and 6½-foot depth. From 8 to 10 gallons of gasoline, costing 16½ cents at the works, were used per day. The material, which was a loam underlain by a stiff gravelly subsoil, was excavated at the rate of about 200 cubic yards in 10 hours. The cost of operation per shift was as follows:

One operator	$4.00
One trackman	2.00
Ten gallons gasoline, at $0.16½	1.65
	7.65

The cost per cubic yard, exclusive of interest and depreciation, was about 3.8 cents. The contract price on 5,000 cubic yards was 12 cents.

Such a machine as this would be well adapted to digging the small ditches in the South that are almost universally put in by hand at a cost of about 25 cents per cubic yard. Even in ground covered with stumps, by using plenty of dynamite this type of excavator could be used to advantage in reducing the cost of small ditches.

In general, it may be said that the dry-land dipper dredge, though applicable to certain conditions, has no extensive use in drainage work, as excavation that is suitable to this machine can usually be handled to better advantage by the drag-line scraper excavator.

THE DRY-LAND GRAB-BUCKET EXCAVATOR.

Dry-land grab-bucket excavators of both the rotary and stationary types are in quite extensive use. A machine of the former type, having an orange-peel bucket, is illustrated in Plate VI, figure 1. The excavator either moves on wooden rollers resting on planks, or is mounted on four trucks which move on a track built in sections so that it can be taken up in front and relaid behind as the work progresses. In the revolving type this shifting of track is ordinarily done by the machine itself.

A nonrevolving, orange-peel excavator with a 1-yard bucket was used in building a levee 10 miles in length and inclosing about 2,500 acres of land. The excavator was mounted on four 4-wheel trucks that ran on 4 lines of track. The machinery consisted of a 60-horsepower boiler and a 30-horsepower double-cylinder hoisting engine. The boom had a swing of 75 feet and a rise of 20 feet. The machine weighed about 50 tons and cost about $4,000. The levee averaged 7 feet high and 6 feet wide on top; it had 2 to 1 slopes on both sides. The material excavated amounted to about 270,000 cubic yards. The cost of labor, fuel, oil, and repairs amounted to $19,989, making the cost of the levee about 7.4 cents per cubic yard, exclusive of interest and depreciation.

THE TEMPLET EXCAVATOR.

All of the machines hitherto discussed cut ditches with more or less rough and irregular slopes and bottoms. Although these features are to a certain extent under the control of the operator, the completed work at best is not equal in appearance nor in hydraulic efficiency to the results obtained by the templet excavators. In the latter type of machine, excavation is accomplished by one or more buckets attached to an endless chain which travels over a guide frame or templet and cuts successive slices of material from the perimeter of the ditch. Although the templet machine cuts a superior ditch where soil conditions are favorable (see Plate VII, figure 2), it can not, in its present development, cope with stumps, rocks, or extremely hard earth.

A form of templet excavator is shown in Plate VI, figure 2. It has a single bucket which moves along a guide frame shaped to the desired cross-section of the ditch. The entire machine may be mounted on caterpillar tractors or on wheels which run on a wooden track.

The ditch section is dug by the excavation from its perimeter of thin layers of material which the bucket carries to the outer ends of the frame and dumps on the waste bank. This machine is made in two sizes, for the construction of ditches with narrow and wide bottoms, respectively. The narrow-templet machine will dig ditches

ranging in size from 3 feet wide and 2½ feet deep up to 19 feet wide and 8 feet deep; while the wide-templet machine will construct channels varying in size from 6 feet wide and 6 feet 3 inches deep, to 32½ feet wide and 12 feet deep.

The excavator is operated either by steam or gas engine. A 25 to 40 horsepower steam plant is necessary, depending on the size of the excavator; or, if an internal-combustion engine is used, from 50 to 80 horsepower is required. The bucket varies in size from ½ cubic yard to 2 cubic yards. An operator and 1 assistant are required to operate the machine.

COST OF OPERATION.

A single-bucket templet excavator was used in southern Louisiana on the construction of 7,825 feet of ditch having a 24-foot bottom width and ranging in depth from 3.5 to 7 feet. The side slopes were 1 to 1, and the width of berm was 15 feet. The total excavation was 43,128 cubic yards. The total cost of this machine on the work was $8,506.22. The soil was a yellow clay with a few spots of gravelly clay, and the top soil was baked very hard. No special difficulties were encountered except that considerable cribbing was necessary to level up the track supporting the excavator when crossing natural water courses; except for these streams the ground was level. Some trouble was also experienced with the traction device, due to the fact that the ditch was larger than that for which the machine was designed. The actual number of working days was 128, 73 days of which were spent in actual digging. The cost of operation per day was as follows: One operator, $3.85; one fireman, $2.28; three deck hands, $6.27; one team and teamster, $5.40. The total cost per day was $17.80. The average daily excavation for the number of days worked was 337 cubic yards. The total cost of operation for 5 months was $3,500.58. Interest and depreciation in that time, at 41 per cent per annum, would amount to $1,452.82, making the total cost $4,953.40 and the cost per cubic yard $0.1149. Table 1 is an itemized statement of cost for the entire work.

TABLE 1.—*Cost of operation of single-bucket templet excavator on a ditch in Southern Louisiana.*

Month.	Labor.		Material.		Fuel.	Total cost.
	Operation.	Repairs.	Operation.	Repairs.		
	Dollars.	*Dollars.*	*Dollars.*	*Dollars.*	*Dollars.*	*Dollars.*
February	170.00	26.00	45.00	20.00	55.39	316.39
March	439.75	48.90	141.92	52.63	158.50	841.70
April	306.59	116.31	122.05	91.34	100.00	736.29
May	499.63	46.80	77.69	5.41	156.92	786.45
June	469.27	56.47	109.37	53.61	131.03	819.75
Total	1,885.24	294.48	496.03	222.99	601.84	3,500.58

TABLE 1.—*Cost of operation of single-bucket templet excavator on a ditch in Southern Louisiana*—Continued.

Month.	Excavation.	Cost per cubic yard.	Distance excavated.	Total number days worked.	Actual number days digging.	Average length dug per day.	Maximum length dug per day.	Average depth.	Maximum depth.
	Cubic yards.	*Cents.*	*Feet.*			*Feet.*	*Feet.*	*Feet.*	*Feet.*
February	4,175.9	0.076	1,115	16	9.45	120.5	195	3.63	5.30
March	10,559.0	.080	1,785	30	18.7	95.4	140	5.62	7.00
April	7,303.0	.101	1,200	26	10.8	111.1	114	5.57	6.70
May	10,151.2	.077	1,850	29	18.1	102.3	120	5.10	5.80
June	10,938.5	.075	1,875	27	16.3	115.03	135	5.38	6.10
Total or av'g	43,127.6	.081	7,825	128	73.35	106.60	195	5.06	7.00

THE WHEEL TYPE OF EXCAVATOR.

The wheel excavator consists of a steel frame mounted on wheels, which supports on the front end an engine and boiler and on the rear end a pivoted steel framework holding the digging wheel, as shown in Plate VII, figure 1. This excavating wheel revolves upon antifriction wheels placed just outside the rim of the wheel. The excavating scoops or buckets are placed on the circumference of this wheel. The front of each scoop is provided with a cutting edge, which slices a thin layer of earth from the trench as the wheel rotates. When the bucket reaches the top of the wheel, the earth falls onto a belt conveyor, which deposits it on the waste bank. The machine can be mounted on caterpillar tractors for use in wet soil. It is built in several sizes, so that ditches with top widths of from 2½ to 12 feet and with smooth side slopes can be dug. The cost of the excavator varies from $4,000 to $12,000, according to the size of ditch it is desired to dig.

There is a wheel type of trench excavator so designed that by adding side knives sloping sides can be dug. This machine is illustrated in Plate VII, figure 2. A series of buckets attached to two parallel chains travel over the circumference of a wheel mounted on a frame, which is supported by a central shaft about which the wheel revolves. The cutting knives slice the earth from the sides of the ditch, the dirt falling into the path of the buckets. The excavator is made in two sizes. The smaller size will dig 5 feet deep, 90 inches wide, and any side slope not flatter than 1 to 1. The larger size will dig 6 feet deep and 10 feet wide. The machine may be mounted on caterpillar tractors. For the small size 4 by 6 foot tractors are used, while the large machine requires 4½ by 11 foot tractors. Either steam or gasoline power is furnished. This wheel excavator is suitable for the construction of small open ditches. It works to the best advantage in a soft, wet soil; under these conditions its average daily output is about 300 cubic yards.

Experience has shown that it is a mistake for a maker to attempt to build one machine of this type that is suitable for all classes of

soil. Attempts to do this have, up to this time, met with doubtful success.

COST OF OPERATION.

Two machines of the wheel type designed to cut a ditch 4 feet deep, 4 feet wide at the top, and 2 feet wide at the bottom, were used on the excavation of some ditches in one of the Gulf States. Each machine was driven by a 28-horsepower gasoline engine. The digging wheel was 15 feet in diameter and the 2 apron tractors each 5 feet by 12 feet. The weight of each excavator was about 30 tons. The first cost of the machine was $5,500 and freight to the point of use was $338.36, making the total cost of each machine $5,838.36. The soil was a hard, yellow, sandy clay overlain by a turfy muck, varying in depth up to 2½ feet. The turf was easily cut, but the hard clay caused excessive wearing on the bearings. A large part of the work was done when water was from 2 to 3 feet deep on the land. The total length of the ditches dug was 165 miles, the average length of ditch being 2,475 feet. The average depth of digging was about 4 feet, with a 4-foot top and 2-foot bottom. The average distance dug per shift of 10 hours of actual running time was 2,250 feet; the maximum distance dug in 10 hours was 6,600 feet. The average yardages per month for the two machines were 13,245 and 13,180 cubic yards, respectively. The average daily outputs on the basis of the actual running time were 1,000 and 1,126 cubic yards, respectively. A part of the time the first machine ran a double shift, which accounts for the higher monthly and less daily average. It required 13 months to complete the work, the actual time of operation being about half this. On account of the excessive wearing on the bearings, caused by the heavy sandy clay, it was necessary to make frequent stops for rebuilding the machines, which operation occupied an average of nearly two weeks. The total excavation was 317,162 cubic yards.

The daily operating expense per 10-hour shift for each machine was about as follows:

	Per day.
One operator, at $100 per month	$4.00
One assistant	2.00
50 gallons gasoline, at 16 cents	8.00
Repairs	6.00
Other charges	12.00
	32.00

The itemized cost for operation for the entire work was as follows:

Labor	$5,172.11
Interest, discount, and exchange	202.05
Maintenance and repairs	2,860.08
General expense	273.10
Management expense	1,600.00
Provisions and cooking (cook's wages)	2,245.91

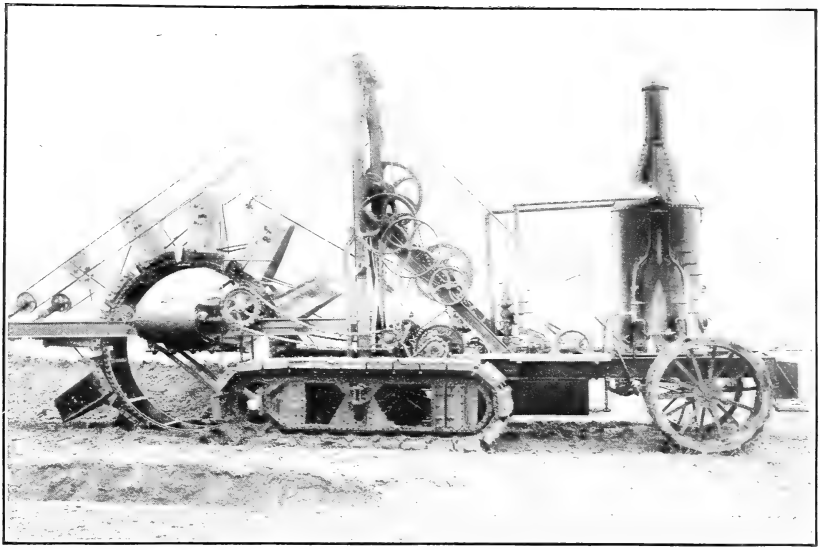
Freight and express	$75.74
Towing	458.19
Gasoline	1,792.22
Other oil	281.49
Teams and livery	932.11
Telephone and telegraph	25.29
Motor-boat operation	540.96
Interest and depreciation on machinery	5,185.00
	21,644.25

Cost per cubic yard, $0.0682.

	Machine No. 1.	Machine No. 2.
Machine running	$917.97	$1,509.66
Machine repairing	1,431.37	771.96
Machine moving	105.20	88.51
Machine bogged	156.90	190.54
Total	2,611.44	2,560.67

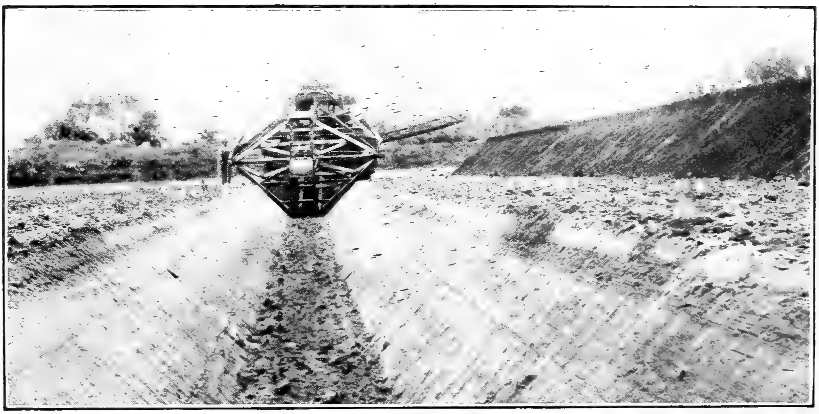
The excessive cost of labor given for the machines when bogged was due to the frequent crossings of a wide, muck-filled bayou which ran the entire length of the district. This bayou was about 1,500 feet wide; the muck ranged from 5 to 15 feet deep and was very soft. No tree roots, submerged timber, or stumps were encountered. The work covered an area of about 7,000 acres, approximately square, which was traversed by parallel canals every half mile. The ditches cut by the excavators were at right angles to these canals and were spaced 330 feet apart. It was thus necessary to turn the machine around and run it light 330 feet for each half mile of ditch cut. The item "moving" is for taking the machine across the canals and for moving from one part of the district to another; it does not refer to the moving between adjacent ditches.

On a project in southern Louisiana a wheel excavator, cutting a ditch 4½ feet deep with a top width of 4½ feet and a bottom width of about 20 inches, was used. The machine worked on comparatively solid ground. Power was supplied by a 28-horsepower gasoline engine. The first cost was $4,000, and freight charges from factory to works were $350. After the machine had been operated for a short time it became apparent that the excavating wheel was far too light and a new wheel was substituted. The soil was a silt loam, firm and uniform but not tenacious. No special difficulties due to soil conditions were encountered in this work. The chief obstacles to rapid progress were at first the weakness of the light excavating wheel, and afterwards the extra-heavy excavating wheel which unbalanced the machine. The tractors were larger than necessary and often broke down when turning on the hard ground. At the time the following cost records terminated, the work had been carried on intermittently for about 18 months; about one-half this time was occupied in repairs. During this time the machine dug 117,000 feet of ditch 4½ feet deep, 45,500 feet 3½ feet deep, and 9,250 feet twice over, the



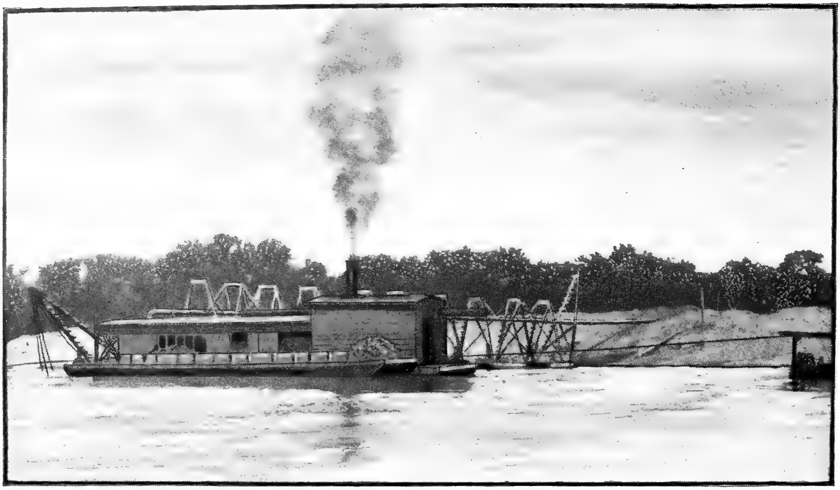
D12398

FIG. 1.—A TRACTION DITCHER OF THE WHEEL TYPE.



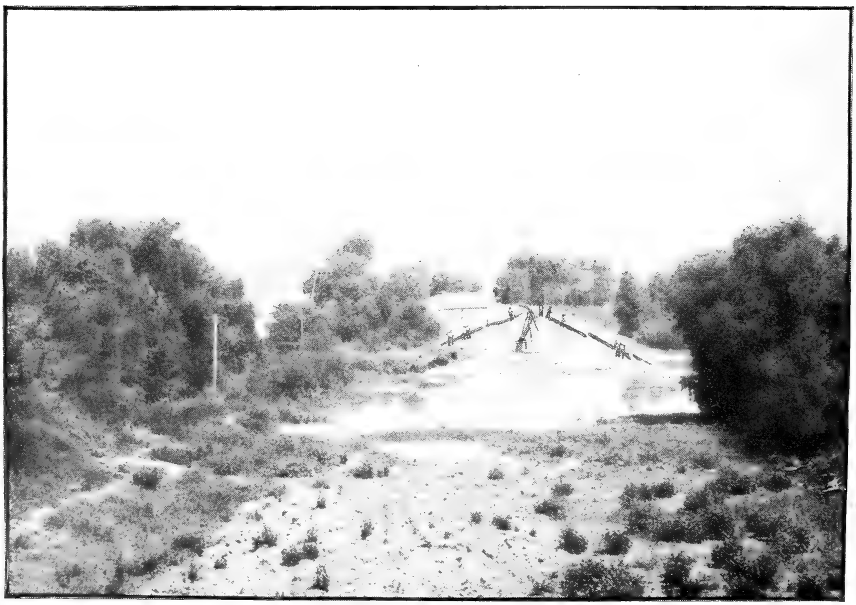
D12399

FIG. 2.—CONVERTIBLE TRENCH AND OPEN DITCH EXCAVATOR.



D12400

FIG. 1.—DREDGE AT WORK AND COMPLETED LEVEE.



D12401

FIG. 2.—CONSTRUCTION OF LEVEE SHOWING SLOPE BOARDS.

LEVEE CONSTRUCTION BY HYDRAULIC-FILL METHOD.

machine making two $4\frac{1}{2}$-foot cuts side by side. The average length of ditch cut per day was 800 feet, while the maximum was 1,950 feet. The daily cost of operation was as follows:

Labor	$5.50
Fuel	4.20
Incidentals	.50
Repairs	2.40
	12.60

The average excavation per day was 410 cubic yards, based on the average of 800 feet of ditch, $4\frac{1}{2}$ feet deep, $4\frac{1}{2}$ feet wide at the top, and 20 inches wide at the bottom. The machine excavated 82,330 cubic yards in 18 months at the following itemized cost:

Gasoline based on 215 actual days' operation (estimated)	$903.00
Repairs, actual cost	860.00
Incidentals, at 50 cents per day	120.25
Labor of foreman, 18 months, at $75 per month	1,350.00
Other labor, two men, $2.50 per day for 250 days	625.00
Interest and depreciation	2,675.25
Total	6,533.50

Cost per cubic yard, $0.0793.

THE HYDRAULIC DREDGE.

The hydraulic dredge has little application in the construction of ditches for drainage purposes, due to the fact that nearly all the drainage ditches are of too small a cross section to be economically dug by this method. This type of dredge probably is, however, the most economical machine existing for excavating very large channels.

The essential parts of the hydraulic dredge are a centrifugal pump and the power to drive it, the whole mounted on a barge. The suction pipe is attached to the pump by a movable joint so that the suction end can be raised or lowered. The material, mixed with water, is drawn through the suction pipe and discharged where desired through a line of pipe sometimes several thousand feet long. Coarse sand and gravel, muck, and silt are easily handled in this way, and by the use of a rotary cutter on the end of the suction pipe, comparatively hard clay can be removed. The machine does not work well, however, where there are stumps, logs, stones, or other such obstructions.

Dredges of this type are suitable for digging ditches 800 or more square feet in cross section, for building levees under favorable conditions, and especially for building up tidal flats and low lands.

COST OF OPERATION.

The following table indicates the cost of operating a hydraulic suction dredge on the New York Barge Canal in 1908. The dredge in question is of modern construction, has a 20-inch discharge pipe,

and cost $115,000. Once during this season the dredge was sunk to the bottom of the canal; otherwise, the work was done under favorable conditions and the excavation made was representative of the capacity of the machine in ordinary clay soil.

Cost of excavation by hydraulic suction dredge on the New York Barge Canal for the season 1908.

Month.	Labor.	Plant.[1]	Material.	Total for month.	Yards excavated.
	Dollars.	*Dollars.*	*Dollars.*	*Dollars.*	
April	3,670.95	408.30	1,900.62	5,979.87	120,673
May	5,169.29	1,367.60	2,558.88	9,095.77	204,838
June	5,615.75	1,677.85	2,263.16	9,556.76	203,474
July	5,835.14	1,735.50	2,446.45	10,017.09	207,520
August	5,985.87	1,631.15	2,320.92	9,937.94	174,395
September	4,993.11	1,692.85	2,430.05	9,116.01	231,473
October	4,834.14	1,791.15	2,573.50	9,198.79	214,438

[1] Interest and depreciation at 15 per cent per annum.

Average cost for the season, $0.0464 per yard.

USE IN CONSTRUCTION OF LEVEES.

It formerly was considered that the hydraulic dredge was not applicable to levee construction for the reason that the large amount of water pumped made it difficult to keep the solid material from spreading over a wider base than desired for the levee. It was generally thought necessary to build ridges to form the toes of the embankment, with earth dry enough to hold the wet material within the desired limits until the solid matter had been deposited; in this manner one layer was added to another until the desired height of levee was reached. The need of this dry material is avoided by methods now in use by which the entire section of the levee is built in one operation.

Plate VIII and Plate IX, figure 1, illustrate the method of forming the desired slopes by means of steel boards about 18 inches wide and 10 feet long, made of No. 14-gauge steel with angle-iron top. These boards are not too large nor too heavy to be easily moved by one man. In Plate VIII, figure 2, the slope boards are easily seen; they are placed at the intersection of the side slope with the natural slope of the end of the fill under construction. Several men equipped with shovels are necessary to distribute the material evenly and to move the slope boards ahead as the levee is built up.

On a section of levee built along the Mississippi River near Burlington, Iowa, a hydraulic dredge consisting of a hull 24 by 80 by $4\frac{1}{2}$ feet, upon which was mounted a centrifugal pump having a 12-inch suction pipe, a 14-inch discharge pipe, a 200-horsepower engine, and a boiler nominally rated at 150 horsepower, was used for the construction. The discharge pipe was carried from the dredge to the

top of the levee by small towers mounted on 14 by 40-foot barges. A strip about 30 feet wide along the center of the site of the levee was grubbed and ploughed. No muck ditch was prepared. The levee was about 14 feet high with an 8-foot crown and 3 to 1 slopes on both sides. The number of men usually employed was about 14, and the fuel used was about 5 tons of good coal in each shift. Two 11-hour shifts built 100 linear feet of completed levee, or 2,700 cubic yards. A dredge of this type costs approximately $15,000, not including the discharge pipe, the barges, and other necessary appurtenances which will add about $5,000, making the total first cost about $20,000 for a plant to build levees by this method.

With hydraulic-fill levees a wide foreshore can be left. There are no borrow pits to aid in probable seepage and consequent failure of the levee. Any side slope wanted for a levee can be built. There is no shrinkage after the embankment is first completed, for the material is thoroughly compacted. The fine material is deposited in the base of the levee where it is most needed to prevent seepage. By using the hydraulic-fill method, a levee can be built across an old bayou or lagoon with as little trouble as on dry ground, which can be done by few machines. Wet, soggy ground gives no trouble in construction. Hydraulic-fill levees, being composed mostly of sand, are proof against damage by burrowing animals.

On the other hand, a 20-foot head with about 600 to 800 feet of discharge pipe are the maximum conditions under which a plant developing only 200 horsepower can operate; greater heights and distances must be overcome by a corresponding increase of power equipment. The dredge must always be in about 8 feet of water to prevent air from being drawn into the suction pipe. It would hardly pay to put such an outfit on a project of less than 250,000 cubic yards.

It has been observed in hydraulic fills made with clay that the tendency to settle is not so marked as when sand alone or sand mixed with some silt is pumped. The tendency of the sand to settle in the bottom of the discharge pipe permits the building of levees having any slope between the natural slope assumed by moist sand and that of a semifluid. By using the slope boards, however, a greater range of side slopes can be had.

MACHINES FOR CLEANING OLD DITCHES.

A floating dredge as a rule is unsuited to cleaning old ditches unless the amount of material to be excavated is large. It is also impracticable to dam up the channel on account of possible damages to the landowners. Moreover, all bridges must be removed if a machine of this kind is used.

A type of the stationary scraper excavator which straddles the ditch has been used quite successfully on the smaller ditches. On

large ditches the top width is too great to permit the use of a machine of this type. The scraper machine of the rotary type, operating from the top of one waste bank, has also been used for cleaning out old ditches. With this kind of machine the banks of the ditch can be trimmed. However, the machine must first level down the old waste bank sufficiently for it to travel over. An orange-peel bucket, instead of the scraper bucket, has also been used on the drag-line machine for cleaning ditches. With the drag-line excavator it is unnecessary to remove bridges, which item effects a considerable saving in cost of cleaning ditches on a large project. The rotary type of scraper excavator is probably the most efficient machine for cleaning ditches.

A small centrifugal pump operated by gasoline power and mounted on a small hull has been used in cleaning out some ditches in Iowa. This device is illustrated in Plate IX, figure 2. The pump, which has a 5-inch suction pipe and two 5-inch discharge pipes, is operated by a 48-horsepower internal-combustion engine which starts on motor spirits and runs on kerosene. The whole equipment was mounted on a hull 28 feet long, 5 feet wide at the bottom, 10 feet wide at the top, and about 4½ feet deep. Immediately in front of the hull were placed five cutter wheels, each 3 feet in diameter and weighing 100 pounds. These cutter wheels were operated by power obtained from the engine. The end of the suction pipe was 5 feet long and 2 inches wide and was placed about 2 feet behind the cutter wheels. Half of the material was discharged on each side of the ditch, beyond the waste bank. The dredge cleaned from 250 to 300 feet of ditch in a day of 10 hours. The excavation amounted to about 1½ cubic yards of earth for every linear foot of ditch. Three men were required to operate the dredge. By taking down one discharge pipe and turning the other lengthwise of the ditch the dredge could easily pass under the bridges. Four men could dismantle the dredge in 2 days and set it up in 5 days. The complete cost of the plant was $3,000. For removing sand and silt from ditches this type of machine is excellent. The dredge works downstream and must have considerable water. The average cost of operation per day was as follows:

One engineer	$3.00
One assistant	2.50
One helper	2.00
Twenty gallons kerosene, at 10 cents	2.00
Total cost per day	9.50

Based on 200 feet of ditch cleaned, the excavation per day would be 300 cubic yards, and cost per cubic yard about 3 cents, exclusive of interest and depreciation. The actual unit cost for the whole job, however, would run very much higher than this, due to delays and repairs.

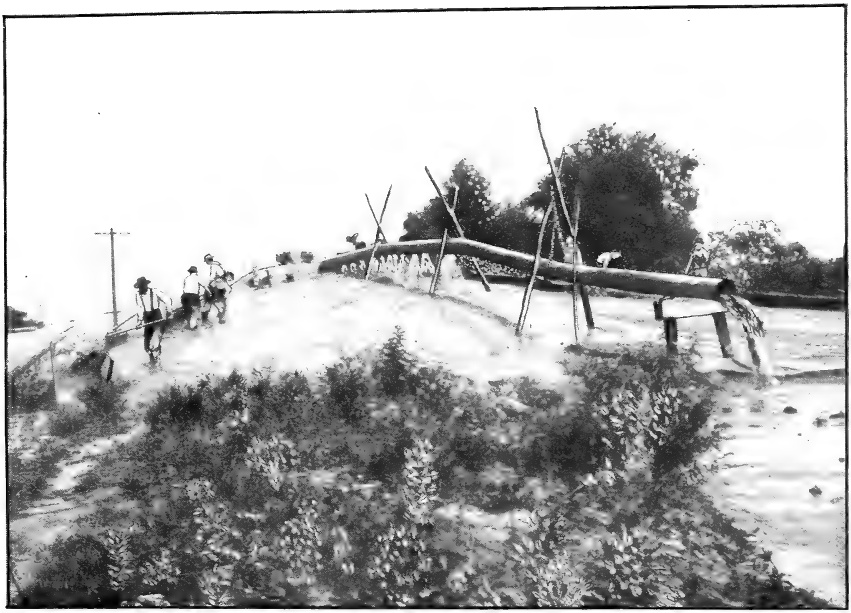


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FIG. 1.—HYDRAULIC-FILL LEVEE CONSTRUCTION SHOWING METHOD OF FORMING LEVEE SLOPES.

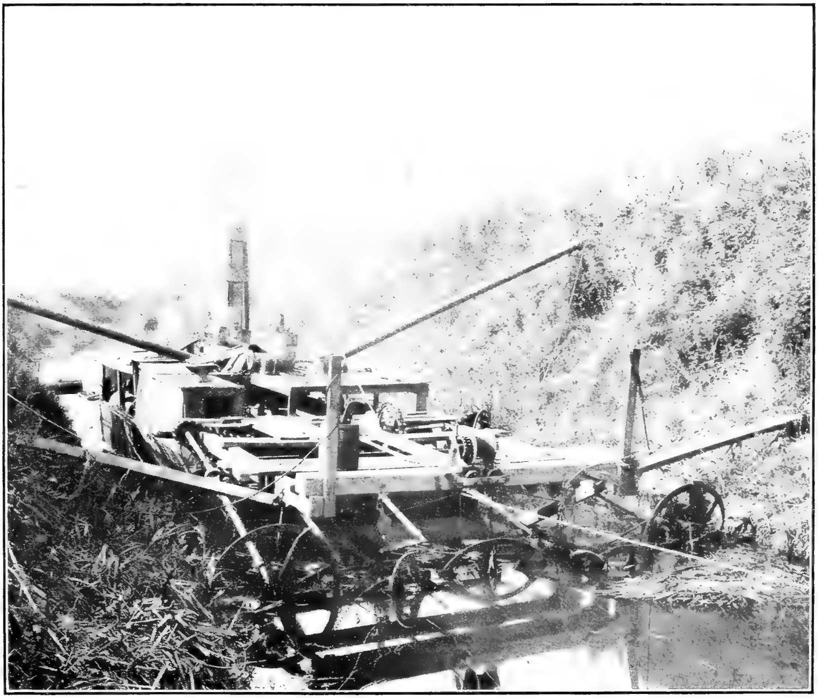

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FIG. 2.—SMALL HYDRAULIC DREDGE USED FOR CLEANING DITCHES.

SUMMARY.

Power machinery is now available which will construct outlet drainage ditches of all sizes, and under all conditions of soil and water, cheaper than can be accomplished by any other method.

The floating dipper dredge is more widely used in drainage work than is any other type of excavating machine. For work through wet land no other excavator will equal it in cheapness of construction of ditches having a cross section of from 100 square feet to 1,200 square feet. It is by far the most efficient machine to use where many stumps will be encountered. Owing to its limited reach it is not generally applicable to levee construction. Dipper dredges as constructed for drainage work range in capacity from one-half cubic yard to 4 or 5 cubic yards; the sizes most commonly used vary from 1 to 2 cubic yards. The smallest dredge costs about $5,000; the cost increases rapidly with the capacity of dipper. The floating dipper dredge should be operated downstream, where practicable.

In general, the clam-shell or orange-peel dredge is not well adapted to ditch construction, especially if there are stumps to handle. Certain types of soil, such as the muck of southern Louisiana, can, however, be handled to advantage with this machine. It is also suited to levee building when equipped with a long boom.

The drag-line scraper excavator is constantly increasing in favor in drainage work. It is especially suited to the construction of ditches and levees of large cross section, where the ground is sufficiently stable to support the machine. The scraper excavator is also suitable for ditch cleaning.

The various forms of so-called dry-land machines find quite extensive use in drainage. The dipper and orange-peel dredges of the dry-land type are suitable for use where sufficient water can not be had to float a dredge. The templet and the wheel types of excavators are applicable to open land where the soil is neither too hard nor too wet. The ditches cut by these latter machines are superior in hydraulic efficiency to those of similar section cut by any other type of excavator. The dry-land machines should be operated upstream.

The hydraulic dredge is not suited to ordinary drainage ditch construction. It has been used to some extent in cleaning ditches, and, with the use of slope boards, has in at least one instance made a satisfactory record in levee construction.

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